

Needs and Opportunities for Improving the Health, Safety, and Productivity of Medical Research Facilities

Michael Hodgson,¹ William Brodt,² David Henderson,² Vivian Loftness,³ Richard McCrone,¹ Gary Roselle,⁴ Arthur Rosenfeld,⁵ James Woods,⁶ and Richard Wright⁷

¹Department of Veterans Affairs, Washington, DC, USA; ²National Institutes of Health, Bethesda, Maryland, USA; ³Carnegie Mellon University, Pittsburgh, Pennsylvania, USA; ⁴Department of Veterans Affairs, Cincinnati, Ohio, USA; ⁵Department of Energy, Washington, DC, USA; ⁶HP-Woods Research Institute, Herndon, Virginia, USA; ⁷National Institute for Standards and Technology (retired), Gaithersburg, Maryland, USA

Medical research facilities, indeed all the nation's constructed facilities, must be designed, operated, and maintained in a manner that supports the health, safety, and productivity of the occupants. The National Construction Goals, established by the National Science and Technology Council, envision substantial improvements in occupant health and worker productivity. The existing research and best practices case studies support this conclusion, but too frequently building industry professionals lack the knowledge to design, construct, operate, and maintain facilities at these optimum levels. There is a need for more research and more collaborative efforts between medical and facilities engineering researchers and practitioners in order to attain the National Construction Goals. Such collaborative efforts will simultaneously support attainment of the National Health Goals. This article is the summary report of the Healthy Buildings Committee for the Leadership Conference: Biomedical Facilities and the Environment sponsored by the National Institutes of Health, the National Association of Physicians for the Environment, and the Association of Higher Education Facilities Officers on 1–2 November 1999 in Bethesda, Maryland, USA. *Key words:* best-practices, built environment, construction, emerging pathogens, healthy buildings, indoor environment, medical research, occupational health, preventive strategies, productivity, sick building, standards. — *Environ Health Perspect* 108(suppl 6):1003–1008 (2000). <http://ehpnet1.niehs.nih.gov/docs/2000/suppl-6/1003-1008hodgson/abstract.html>

Medical Research Converges with National Construction Goals

Medical research occurs almost exclusively in hospitals and laboratories and associated offices, conference rooms, and classrooms. A variety of Federal standards and guidelines from the Occupational Safety and Health Administration and the Centers for Disease Control address topics such as laboratory safety, blood-borne pathogens, and tuberculosis control. Similarly, architectural and engineering standards from the American Institute of Architects, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the Illumination Engineering Society of North America, the National Fire Protection Association, and other professional organizations address various interests within these environments. No unified guideline has evolved, however, that documents the need for health and productivity considerations, identifies current gaps, or considers more than minimal requirements, such as the best-practices approaches that have recently been successful in ergonomics, patient safety, and noise control.

This article is the summary report of the Committee on Healthy Buildings for the Leadership Conference: Biomedical Facilities and the Environment sponsored by the National Institutes of Health, the National Association of Physicians for the

Environment, and the Association of Higher Education Facilities Officers on 1–2 November 1999 in Bethesda, Maryland, USA. The Committee on Healthy Buildings grew out of activities of the National Science and Technology Council's Subcommittee on Construction and Building (NSTC) and the Public Health Service's Engineering Professional Advisory Committee's Subcommittee on Building Design and Construction (EPAC). The NSTC, with representation from many Federal agencies including the Public Health Service, promotes the national construction goals, among which are *a*) 30% increase in productivity and comfort, *b*) 50% fewer occupant-related illnesses and injuries, and *c*) 50% reduction in construction work illnesses and injuries (*1*).

The EPAC consists of engineers and architects, many of whom have professional experience in facilities engineering or industrial hygiene. On the basis of the interagency collaboration fostered by the NSTC and the EPAC, the conference sponsors incorporated the topic "healthy buildings," which is the consideration of health in the indoor environment, into the conference agenda. As it was a late addition to the conference, the session organizers selected key individuals to represent the broad spectrum of current research.

This report combines the introductory statements and the three formal presentations.

The presentations consisted of *a*) a detailed description of engineering solutions to emerging health issues in the hospital environment; *b*) productivity and health in the office environment; and *c*) a prioritization of topics needing implementation or the development of research solutions. Subsequent to the conference, the EPAC prepared a memorandum to the Surgeon General recommending

- Establishment of a link between the medical and building communities to identify universally accepted standards and criteria for health in the indoor environment, and promote continued research on the subject of the interaction between the built environment and human health.
- Formation of a Surgeon General's task force drawn from the medical and building communities within the public and private sectors, including Federal, state and local agencies, professional organizations, universities, and other concerned groups to clarify a healthy buildings research agenda within the context of the national health goals as identified in *Healthy People 2010* (*2*).

Scientific Background

Although the term "sick-building syndrome" has been in use for more than 20 years, no valid scientific definition exists (*3*). Despite years of interest and concern, many employers and professionals remain unwilling to invest in analyzing the impact of the indoor environmental quality on the comfort, health, productivity, and safety of occupants. Public discussion of the sick building syndrome generally focuses on the lack of knowledge of the subject, and on its psychologic implications rather than on the facts as indicated in Table 1. European studies have repeatedly identified widespread discomfort and health deficiency symptoms among office workers

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Address correspondence to W. Brodt, NIH, Bldg. 13, Rm. 2W48, Bethesda, MD 20892 USA. Telephone: (301) 402-1626. Fax: (301) 402-7182. E-mail: william_brodt@nih.gov

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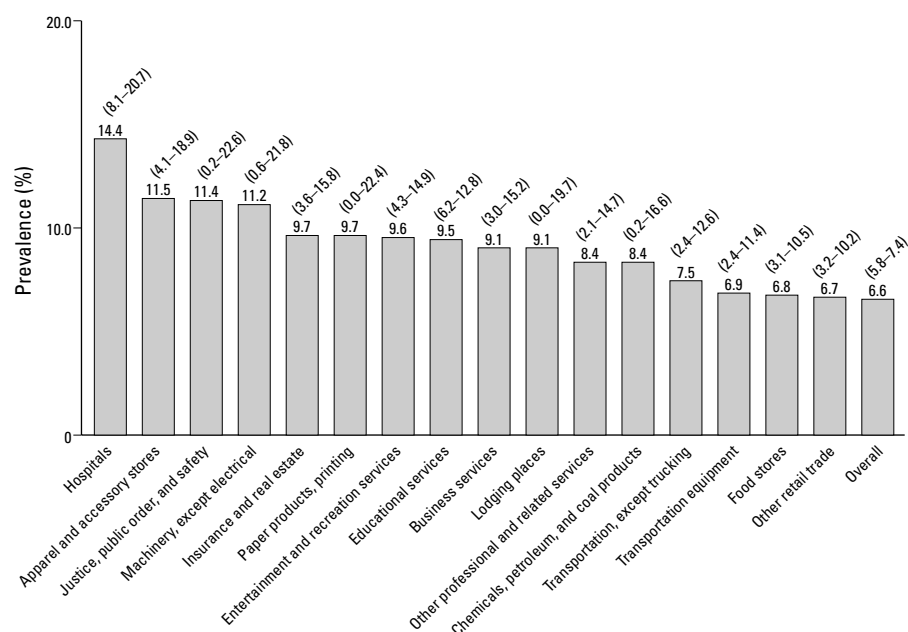
Table 1. Building factors.^a

Personal factors
Atopy/allergies
Dry skin (positive stinger test)
Gender
Job description
Age
Building factors
Mechanical ventilation systems
Inadequate outside air
Inadequate air distribution strategies
Moisture incursion
Crowding
Thermal comfort
Acoustics
Lighting
Work factors
Photoduplication
Carbonless copy paper
Work stress
Specific pollutants
Volatile organic compounds (complex mixtures)

^aData modified from Malkin et al. (5); Wargocki et al. (23); Brundage et al. (25); Mendell (31); Wyon (32); Hodgson et al. (34); Ten Brinke et al. (35); Crandall and Sieber (36); Rosenstock et al. (37); Mendell (38); and Rosa et al. (39).

(4), and Malkin et al. described the prevalence of symptoms in a sample of the hundreds of buildings investigated by the National Institute for Occupational Safety and Health (NIOSH) (5). Regular work-related eye irritation and dryness occurred in more than 30% of office workers, headaches in 25%, and nasal symptoms in more than 20%. Even if the symptoms alone were not to affect productivity, evidence supports decreased task performance (6). Medications taken for nasal symptoms affect task performance (7). Indoor environments, meanwhile, represent the single most common cause of work-related asthma in the United States, representing approximately 10% in the early 1990s (8) and more than 25% in the experience of specific clinics with an interest in the topic (9). Other less frequently occurring diseases may affect large groups of individuals and affect organizational function rather than individual performance, as occurs during outbreaks of health problems in buildings even in the health care environment (10–12).

Health issues generated by the indoor environment are of significant interest to the medical research establishment, whose activities occur in the built environment. Hospitals represent one of the three largest groups of buildings generating health hazard evaluation requests for the NIOSH under the Health Hazard Evaluation program. Schools and office buildings are the other two groups. Offices, conference rooms, and lecture halls have all generated similar complaints and investigations among health care workers and in the public-at-large (13). Recent data suggest that 14.4% of health care workers have asthma as compared to 6.6% of the population at large

**Figure 1.** NIOSH asthma slide. Adapted from Rosa et al. (39).

(Figure 1), although the reason remains unclear. This may be due to increased infection rates (14,15), latex, and glutaraldehyde, or to other aspects of the building (13).

The Emerging Pathogens Guidebook

G. Roselle and R. McCrone discussed the *Emerging Pathogens Guidebook* (16), recently issued by the Department of Veterans Affairs. Hospitals are communities as complex as office and mixed-use buildings and schools. They represent both a community of patients with diseases and people from the various professions and trades that treat them, creating a mutually interdependent environment that challenges us to acknowledge fundamental public health truths. Hospital-acquired infections affect approximately 2 million patients annually at a direct patient cost of \$3.5 billion (17). The illnesses and associated costs should stimulate us to examine the relationships between various community members and how disease is transmitted. We must, after all, provide for the safety of all members of the community. Approximately 10% of hospitalized patients acquire such infections, and 15,000 die annually. In comparison, 7 die and 138 persons are injured in hospital fires per year. What do we do differently? Fire suppression in health care institutions is a complex program of sophisticated engineering controls, vigilant work practice controls, and personal protective equipment. In contrast, similar engineering controls have not been systematically applied to the problem of nosocomial infection. The various members of the health care community have responsibility for sharing their knowledge and

protecting each other from pathogens just as they work together on fire prevention. Preventing the adverse effects of pathogens on a community level may actually be easier, more straightforward, and more effective than relying on individual behaviors to make the community safe. Tuberculosis and nosocomial infections such as staphylococcus, enterococcus, and aspergillosis are conditions that support the logic and benefits of intervention and prevention through this multidisciplinary collaborative approach.

Traditional disease and injury control in occupational health relies on a hierarchy of engineering controls, administrative controls, and personal protective devices. The sequence in which they are desirable does vary at times; it may also vary from the perspective of individuals in the community. Nevertheless, control strategies that rely upon building structures and systems, such as: *a*) physical barriers, *b*) heating, air-conditioning, and ventilation controls, and *c*) continuous monitoring of conditions, are likely to be more effective than strategies that rely primarily upon the personal protective actions of individuals, such as: *a*) donning respirators, *b*) leaving specific areas in time, and *c*) washing hands correctly, which rely upon human memory and willingness to do. Still, facilities may be redesigned to facilitate the performance of tasks such as handwashing through correct placement of hand-washing facilities in relation to entry and primary function in the room. The replacement of doors with privacy screened openings is frequently designed into large public restrooms such as those found in airports, but doors are required in patient rooms for sound control, fire protection, and

Table 2. Emerging pathogens.

Agent	Source	Disease	Transmission	Precautions	Engineering challenge
Enterococci (bacterium)	Gastrointestinal tract	Local ("seeded")	Fecal–oral (people, colonized surfaces), person-to-person	Handwashing, human waste disposal	Bedpan redesign, single patient toilets, environmental cleaning, handwashing facility/flow design rooms
Aspergillus (fungus)	Decaying vegetation, dust, soil	Aspergillosis, hypersensitivity pneumonitis	Inhalation of spores (no person-to-person transmission)	Air filtration, moisture control, dust control, including during construction)	Air handling (cleaning and directional air flow), reservoir identification (rotting wood, false ceilings), source control (dirt, moisture, bird populations), envelope protection (water leaks, air infiltration)
Legionella (bacterium)	Water, soil	Legionellosis (pneumonia)	Inhalation of aerosols (not person-to-person) distribution systems	Prevent Legionella colonization and aerosolization, control colonized Legionella sources	Prevent biofilm containing Legionella in potable and hot water, cooling towers, evaporative condensers, whirlpools, water system repairs, construction
Tuberculosis	Droplet nuclei	Pulmonary tuberculosis	Person-to-person and surface-to-person	Identify sources, contain sources, removal/inactivation of bacteria	Maintain pressure relationships, filtration, germicidal UV
Viral diseases	Droplet nuclei	Influenza, measles, varicells	Person-to-person	Source identification, vaccination	
Gram negative bacteria	Dental water lines	Pneumonia	Aerosols	Maintenance protocols	Design systems to maintain bacterial counts at undetectable levels

infection control. Engineers and architects, as facility and system designers, play a major role in controlling diseases in the health care environment. Fundamentally, their willingness to implement preventive strategies, rely on and facilitate engineering solutions, and remove barriers to good practices describes the basic principles that lead to creating a healthy work environment.

Facility planning and design rely on teamwork to identify functional requirements, maintain relevance and credibility, communicate ideas and needs effectively, and articulate functional problems that require a design solution. Construction supervision and management similarly involve teamwork in converting the design documents into an operational facility. In the best built and operated facilities, the maintenance and operations staff works with the design team to assure that the designed facility will be maintainable, and the operations and maintenance program will fulfill the designed responsibilities. Engineering and infectious disease specialists at the Department of Veterans Affairs incorporated many of these engineering concepts as they developed the *Emerging Pathogens Guidebook*. This resource manual addresses various airborne and fecal–oral hazards in the hospital setting. It is a guidebook that presents a summary of important pathogens juxtaposed with engineering and medical control strategies for use in the hospital environment. The range of microbial agents implicated in disease requires overlapping and differing strategies for each. The essential content is presented in Table 2.

One of the most important lessons from the Emerging Pathogens Project has been the importance of interdisciplinary work. Health care providers, medical scientists, safety specialists, and engineers worked together to define

sources, routes of transmission, intervention strategies, and implementation strategies. Such teams were necessary at all phases from initial conception through program development and implementation. Although such interdisciplinary approaches are called for in indoor environmental work, few have been implemented as broadly as in the health care environment for the specific topic of infection control. At least one major reason for this approach, and its future success, is the recognition by the Joint Commission on Accreditation of Healthcare Organizations of the role that managing utility systems has in issues of organization-acquired illness and infection. Beginning in 2001 managing pathogenic biological agents in cooling towers, domestic hot water, and other aerosolizing water systems must be included in the Utilities Systems Management Plan. This represents a beginning.

Workplace Health and Productivity

A. Rosenfeld of the U.S. Department of Energy and S. Kumar of the Lawrence Berkeley Laboratory presented the Workplace Health and Productivity Project. In 1994, as previously mentioned, the NSTC (18) selected workplace health and productivity as a topic of concern, together with health and safety of construction workers. Specifically, it sought to define the relationships between physical attributes of the workplace and workers' performances and health. This study is funded by the U.S. Departments of Commerce, Education, Energy, Health and Human Services, Veterans Affairs, General Services Administration, and Environmental Protection Agency. The objectives are to review the existing knowledge critically, assemble a bibliographic data base, and stimulate and facilitate

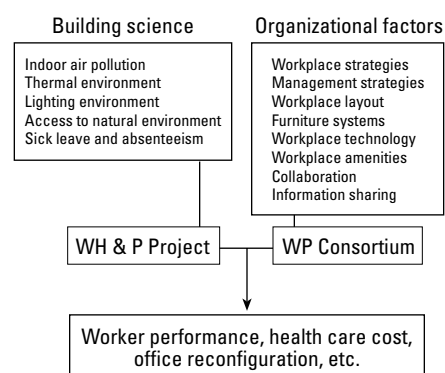


Figure 2. The Workplace Health and Productivity Project in context. WH & P, workplace health and productivity; WP, workplace. Adapted from the Workplace Health and Productivity Project (40).

new productivity and health research. The bibliography compiled by this project currently consists of approximately 500 articles. The internet sites for the bibliography are noted in the caption to Figure 2, which shows the issues addressed by the project.

A major source of interest arises from the recognition that construction, operating, and maintenance costs over the facility life generally comprise only approximately 10% of the total costs of owning and operating buildings, with salaries of occupants comprising the remainder. Even minor changes in productivity have the potential for offsetting relatively major costs in infrastructure support. For example, a 50% increase in energy costs, amounting to approximately 1% of the total building costs for owners, would be offset by a 1% increase in productivity (19–21). In fact, environmental parameters that are frequently uncontrolled, such as thermal gradients, have major productivity impacts by themselves (21).

The built environment may influence health through a number of routes. First, environmental characteristics such as temperature, lighting, odor, and noise levels influence productivity at the workplace. Higher temperatures, i.e., inadequately air-conditioned spaces, lead to decreases in workers' abilities to concentrate (21). This is one major justification for careful implementation of ASHRAE Standard 55-1992 Thermal Environmental Conditions for Human Occupancy (22).

Odor pollution, controllable through ventilation or through removal or exclusion of point sources, is clearly associated with decreased task performance, even in quasi-experimental field studies requiring sustained concentration (23). Unfortunately, odors have been ignored frequently or at least discounted as relatively unimportant (24). Taken as a whole, the evidence is quite convincing that we could achieve major gains in productivity for researchers by producing better environmental quality.

Far more controversy exists over whether infections are associated with indoor environments and whether excess rates of viral disease may be controlled through ventilation, humidity control, and other intervention strategies such as filtration. Since the study of Brundage et al. (25), this topic has been discussed widely. Others have been unable to replicate the relationship with ventilation (26). More important, the relationship of the various known modes of transmission remains

uncertain. Data clearly support both airborne droplet nuclei and hand-to-hand transmission (27–29). Given the relationships of point sources, local dilution gradients, and general dilution ventilation, it remains unclear how strongly increased filtration or increased levels of general dilution ventilation could lower infectious transmission rates. Still, Fisk (21) has laid a very persuasive case for considering this likely. A research project of D. Milton, currently in the field data collection stage, will provide rigorously controlled data.

Table 3 provides an overview of the studies supporting this hypothesis. The total annual estimated health and productivity benefits are estimated by Fisk to range from a low of \$23 billion to a high of \$56 billion, as shown in Table 4.

The Workplace Health and Productivity Project has a broad strategy over the next few years to include not only physical and building science aspects but also organizational factors.

Architectural/Engineering Research for a Healthy Indoor Environment

V. Loftness, Professor of Architecture of Carnegie Mellon University, spoke on research for a healthy environment (30). Despite an international conference series called "Healthy Buildings" held triennially since the mid-1980s, and a proliferation of conferences and publications on indoor air or indoor environmental quality, it is unlikely that the majority of decisions about building

construction and maintenance contribute positively to long-term health outcomes. Furthermore, despite much knowledge reported at the conferences, both in publications and in professional discussions, widespread poor building practices still contribute to discomfort and ill health. Well-known examples, commonly implemented, that generate poor air quality include the design of deep, sealed buildings, indifference to the local climate, smaller proportions of the budget for maintenance and operations, and constrained budgets for building alterations. Mechanical system design remains quite unsophisticated: worst-case system sizing with large control zones leads to widespread discomfort. Technology and spatial layout changes are often unaccompanied by system modifications and air rebalancing. The practices of fast-tracking building construction, permitting occupancy of a building before completion of testing and balancing of building heating, ventilation, and air-conditioning systems, and renovating a building during ongoing occupancy all tend to lead to preventable pollutant exposures. Conversion of unsuitable spaces such as garages and warehouses presents work spaces without expected amenities. The combining of thermal conditioning and ventilation remains the standard environmental control strategy in the United States.

Table 3. Influence of buildings on respiratory disease.^a

Setting	Populations compared	Health outcome	Findings
U.S. Army barracks (25)	Recruits in modern (low ventilation) vs recruits in older barracks	Respiratory illness with fever	50% higher incidence of respiratory illness in modern barracks
U.S. Navy barracks (46)	Recruits in barracks with UV radiation of air vs those in barracks without UV	Respiratory illness with fever	23% decrease in respiratory illness with UV radiation
Finnish Office (45)	Workers with roommates vs workers without roommates	Common cold	Workers with roommates had 20% higher risk of two or more common colds per year
Antarctic Station (48)	Residents of smaller vs larger quarters	Respiratory illness	100% higher incidence of respiratory illness for residents of smaller quarters
New York State schools (47)	Students in fan-ventilated vs window-ventilated classrooms	Respiratory illness and absence	70% more illness and 18% more absence in fan-ventilated classrooms
Four U.S. nursing homes (41)	Residents of single nursing home with no recirculation of ventilation air and less crowding of common areas vs residents in three homes with recirculation and more crowding	Culture-confirmed type A influenza and total respiratory illness	76% less influenza and 50% less total respiratory illness in nursing home with no recirculation and less crowding
U.S. jail (42)	> 80 ft ² vs < 80 ft ² space per occupant and high vs low CO ₂ (i.e., low vs high ventilation per occupant)	Pneumococcal disease	Significantly higher incidence if <80 ft ² space, 95% higher incidence if in cell type with high CO ₂ concentration (i.e., with low ventilation)

^aData adapted from Fisk (21), Husman et al. (43), and Husman (44).

Table 4. Potential health and productivity benefits.^a

Source of productivity gain	Potential annual health benefits	Potential U.S. annual savings or productivity gain
Reduced respiratory disease	16–37 million avoided cases of viral illnesses	\$6–14 billion
Reduced allergies and asthma	10–30% decrease in allergy symptoms	\$2–4 billion
Reduced sick building symptoms	20–50% reduction in sick building symptoms	\$15–38 billion

^aData adapted from Fisk (21).

Table 5. Indoor environments research priorities.

Causes and prevention of building-related health effects
Building-influenced communicable respiratory infections
Building-related asthma and other allergic disease
Nonspecific building-related symptoms
Building science and technology
Indoor pollutant characterization and measurement
Relationship of indoor pollutants to building and ventilation factors
Ventilation rate measurement and control
Social and economic influences on the implementation of health-protective features and practices in buildings
Social and economic influences on indoor environmental quality-related decision-making in buildings
Missing or inadequate cost/benefit information related to indoor environmental quality and health

However, it has fallen out of favor in many parts of Europe and elsewhere, where dual air-handling systems are being installed for ventilation and temperature control, and buildings are generally designed with windows that may be opened to permit additional ventilation on the occasional days in which temperature and humidity prompt occupants to open them. Such heating, ventilating, and air-conditioning system designs have been demonstrated to be effective and efficient in European locations, with energy costs much higher than typically encountered in the United States.

There is widespread recognition of the presence of office worker symptoms and their relationships with environmental factors beyond thermal comfort. These include lighting and ventilation (4,30), as well as exposure to carpets, photocopiers, and carbonless copy paper (4). Control of odors (23) and particulates (32) have been shown to reduce sick building syndrome symptoms. In addition, a growing body of literature suggests that volatile organic compounds are associated with symptoms of mucosal irritation (33–35). Investigations of series of problem buildings have suggested that in the 1970s and 1980s approximately one-half of all problems were primarily due to ventilation systems, although this may have improved in recent years (20,36).

Barriers to creating healthy buildings exist on many levels, including inadequate scientific knowledge and inadequate willingness to implement what we know. For example, we do not have a good definition of what is considered a healthy building, i.e., operational criteria in every domain. There is no national research repository, the existing level of research support is inadequate, and often a health-sciences basis for engineering standards is simply absent from the building design, construction, operations, and maintenance life cycle. The process of constructing buildings is most often based on least-cost approaches, with increasingly short time frames in design, construction, and ownership. There is little feedback from litigation into design, operations, and maintenance. Even where maintenance is undertaken systematically, the records necessary to document the relationships between building performance and occupant health are generally unavailable. Life-cycle costs, though available in models, are often not realistic.

Nevertheless, the healthy buildings concept, with a focus on health, offers a range of opportunities, including sustainability and regionality in architecture. It also offers access to new architectural forms and individual pleasures, such as through the intelligent workplace at Carnegie Mellon. Most important, it

has the potential for major improvement in performance of building occupants, from students in schools with day lighting to improved surgical outcomes in hospitalized patients.

The rules and guidelines for creating healthy buildings must respect the need for operable windows and fresh-air architecture, i.e., campuslike layouts with green space. We must recognize that mechanical systems inadequately designed and operated may not only generate pollutants on their own but also circulate pollutants from other indoor components such as office furniture and machines. Most important, individual control of ambient conditions appears increasingly to be the key to worker satisfaction and perceptions of health.

Health Sciences Considerations

This conference committee is not the first to identify the built environment as an important health issue. Recently NIOSH led more than 500 public and private partners in the development of a National Occupational Research Agenda (36). The Agenda identified 21 priorities in three categories: new technologies, research methods, and work environments. Health related to indoor environments was identified as one of those priorities. Twenty-one teams were formed with NIOSH, private sector, labor, and academic

Appendix. Healthy Buildings Session Planning Committee.

William Brodt (Session Chair)
National Institutes of Health
Building 13, Room 2E42
Bethesda, Maryland 30893
Telephone: (301) 496-4941
E-mail: william_brodt@nih.gov

Engineers Professional Advisory Committee Representatives

Thomas Bedick (EPAC Chair)
National Institute of Environmental Health Sciences
Building 102, Room S117
P.O. Box 12233
Research Triangle Park, North Carolina 27709
Telephone: (919) 541-3327
E-mail: bedick@niehs.nih.gov

Charles Blumberg
National Institutes of Health
Building 13, Room 2E65
Bethesda, Maryland 20892
Telephone: (301) 496-3860
E-mail: blumbergc@exchange.nih.gov

Clarence Dukes
National Institutes of Health
Building 13, Room 2W48
Bethesda, Maryland 20892
Telephone: (301) 402-0017
E-mail: dukesc@exchange.nih.gov

Daniel Hightower
University of Kansas Medical Center
3901 Rainbow Boulevard, Building 48
Kansas City, Kansas 66160-5301
Telephone: (913) 588-7988

Kenneth Martinez
National Institute for Occupational Health and Safety
4676 Columbia Parkway, MS R11
Cincinnati, Ohio 45226
Telephone: (513) 458-7147
E-mail: kfm1@cdc.gov

Leo Stander
U.S. Environmental Protection Agency
Washington, DC

Mitchell Williams
National Institute of Environmental Health Sciences
Building 102, Room S117
P.O. Box 12233
Research Triangle Park, North Carolina 27709
Telephone: (919) 541-3327
E-mail: william7@niehs.nih.gov

Speakers and Session Planning Participants

David Henderson (Speaker)
National Institutes of Health, MSC 1504
Building 10, Room 2C146
Bethesda, Maryland 20892
Telephone: (301) 496-3515
E-mail: dhenderson@nih.gov

Michael Hodgson
VHA (136)
810 Vermont Avenue., NW
Washington, DC 20420
Telephone: (202) 273-8353
E-mail: muh7@mail.va.gov

Vivian Loftness (Speaker)
Department of Architecture
Carnegie Mellon University

Pittsburgh, Pennsylvania 15213-3890
Telephone: (412) 268-2350
E-mail: loftness@andrew.cmu.edu

Richard McCrone (Speaker)
VHA
810 Vermont Avenue., NW
Washington, DC 20420
Telephone: (202) 273-3880
E-mail: mccric@hq.med.va.gov

Gary Roselle (Speaker)
VHA
810 Vermont Avenue., NW
Washington, DC 20420
Telephone: (513) 475-6317
E-mail: gary.roselle@med.va.gov

Arthur Rosenfeld (Speaker)
California Energy Commission
1516 9th Street
Sacramento, California 95814
Telephone: (916) 654-4930
Fax: (916) 719-7829
E-mail: arosenfe@energy.state.ca.us

James Woods
HP-Woods Research Institute
104 Eldon Street
Herndon, Virginia 20170
Telephone: (703) 471-4000
E-mail: jwoods@hpwoods.org

Richard Wright
20081 Doolittle Street
Montgomery Village, Maryland 20866-1354
Telephone: (301) 977-9048
E-mail: dickwright@erols.com

representation, including one team on indoor environments. Table 5 presents an overview of the research priorities identified by that group. The topics are similar to those identified by the panel presenters.

Summary

The next generation of medical research facilities must well support the productivity, safety, and health of its occupants if our investments in medical research are to be effective. However, health and safety professions, environmental design professions, builders, and facility owners, managers, and maintenance technicians are all too frequently ill-prepared to design, construct, operate, and maintain medical research facilities that will provide productive, safe, and healthy environments for their occupants.

- Health, safety, and human factors professions lack the knowledge to define quantitatively how the parameters of the built environment affect human productivity, safety and health.
- Environmental design professionals consequently lack the knowledge and practices required to provide an environment optimally supportive of the facility's intended use. When general guidelines are available, they frequently lack a scientific basis. For example, surgeons cannot work in the dark, but what precise qualities of light should be provided for the surgeon? Similarly, air changes are important in a surgical suite, but what is the scientific basis for the standard for a particular type of surgical facility?
- Facility owners lack the knowledge needed to define the investments in facilities that will optimize their medical research programs, and facilities managers lack the knowledge needed to effectively operate and maintain their facilities for maximum productivity, safety, and health.

A significant component of the nation's medical research program should be devoted to cooperative research between health scientists and practitioners and environmental design researchers and practitioners to provide the knowledge base and recommended practices needed for effective investments in productive, safe, and healthful medical research facilities. This investment is essential to the success of the nation's medical research program. Because of the diversity of medical research facilities, the knowledge gained will be applicable to improvement of all the nation's constructed facilities, including homes, schools, offices, stores, and factories.

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